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ART. I. — VOLCANISM AND MOUNTAIN-BUILDING.

IN two articles published in previous numbers of this Review (Vols. CVIII. page 578, and CIX. page 231) we have discussed the phenomena of earthquakes and volcanoes, endeavoring to convey in popular language some idea of the nature, extent, and frequency of these remarkable manifestations of the internal forces of the earth. In the last of these two articles it was suggested that occasion would be taken to continue the consideration of the subject, and to endeavor to explain, or at least throw some light on, the nature and connection of the chief causes which have been concerned in carrying on that complicated series of geological dynamics which we include under the comprehensive term "volcanism," and of which the earthquake and volcano are two of the most striking manifestations. The subject is one which has always commanded the attention of geologists, and suggested, or even provoked, discussion among them. The difficulties which it presents, however, become apparent, when we learn, through examination of the printed records of these discussions, how little agreement there is among geological authors, and how widely they differ in regard to points which, as one would suppose, ought long since to have been settled.

We have repeatedly, in the course of the preceding articles, referred to the intimate relationship existing between the phenomena of earthquakes and volcanoes, — a relationship which can hardly fail to have become apparent to all who have given even a limited amount of thought to the subject. We have now, however, to go one step further in the same direction, and show how the consideration of the subject of volcanism leads most directly and naturally to that of the formation of mountain chains, or, in still more general language, to the study of the forces which have drawn the outlines of the continents and moulded the surface of the earth into its present relief.

The difference of elevation between the summit of the highest land and the bottom of the deepest ocean is but trifling, as compared with the whole diameter of the globe, yet of what immense importance in the economy of nature are our mountain chains, and how thoroughly are our most weighty interests and avocations dependent on the form and elevation of the continental masses! Mountains as geographical and geological facts are of the highest significance to the student of natural phenomena, in whatever light he considers them. As agents in determining the character of the climate, the courses of rivers, the nature of the soil, the migrations of nations, the distribution of languages, manners, and customs; in short, in their relations to man and nature, from the point of view of physical geography, they play the leading part. As permanent records of past geological changes in the history of the earth, mountains are all important to the student of geology. What would this branch of science be, without mountains and the study of mountains! The results of the dynamics of the globe are registered in the mighty ridges which encircle it, and mark the outlines of its continents and oceans. Indeed, we can hardly conceive of the present order of things as existing at all without these visible results of the manifold causes which have worked together to make the earth habitable.

Hence, the study of the structure and mode of formation of mountains is the study of the greatest problems with which the science of geology presents us. Thoroughly to work out and comprehend the structure of all the mountain chains of the world would be little different from thoroughly working out and comprehending its geology. There is hardly a problem presented by the science which would not find its application in some one of our mountain systems. Orography, then, or the study of the structure of mountain chains, is the study of geological phenomena on the largest scale and from the most generalized point of view.

It cannot fail to have been impressed on the mind of the reader of the preceding articles, that there is an intimate connection, in the character of the results at least, between the forces by which volcanic and earthquake action is kept up and mountains originated. A volcano is, in fact, a mountain, and to the popular mind there is little difference between an isolated elevation and a group or line of them; between a mountain and a chain of mountains, in short. But not a few of the latter are almost or quite exclusively aggregations of volcanic material; and when we come to rocks which are eruptive, that is, which have been poured forth from the interior of the earth, although not technically volcanic, we find that these constitute a large portion of a great many mountain chains, and especially of the highest and grandest. And the more we look into the matter the more we shall be convinced that the formation of mountains and the development of continents are also closely correlated phenomena. Mountains are but the skeletons of the continents. Wherever a lofty chain of mountains has been raised above the sea-level, there is a central mass with a tendency to grow and spread itself laterally, under the influence of denuding agencies; and, unless counteracted by a general subsidence, there will be a steady increase of breadth of the region, at the expense of the height of the more elevated portion. If the material is carried down and deposited under the ocean, then, whenever there is a change in the relative level of sea and land, so as to bring the newly formed strata above the water, these will be found to present evidences of the conditions under which they were deposited, in the form of marine fossils, which will be more or less abundant, according as the physical conditions varied at the time the deposition took place. If two chains of mountains are so situated with respect to each other that continental growth may take place between them, the process will, of course, be the more rapid, and the newly made land will cover a proportionably greater area. Every continental mass, then, will be found on analysis to consist of one or more chains or groups of mountains, and large areas of lower land which has been derived from the long-continued erosion of the more elevated regions. An examination of good topographical maps of the different continents will show this relation most clearly; especially if aided by sections across the land-masses transverse to the direction of the leading chains of mountains which traverse them.

It is clear, then, that when looking at the subject from the broadest point of view, and endeavoring to make out what agents of geological change have been most widespread and general in their action, we cannot separate the phenomena of volcanoes and earthquakes from those of mountain-building and continental growth. One key must give access to all the mysteries of geological dynamics. The nature of this key was first rather vaguely shadowed forth by Leibnitz in his "Protogæa"; but the key itself was not really forged until long after, when Humboldt began to group the physical phenomena of the universe into one harmonious picture, or cosmos. Leibnitz recognized the fact that the earth had cooled from a condition of igneous fusion, and that in this cooling inequalities of the surface would be likely to have arisen. But it was reserved for Humboldt to announce a cause of volcanic action which would be always operative, both through the past geological ages and in all future time. As first enunciated by him, half a century ago, it was intended to be applied solely to volcanic phenomena, and was thus expressed: "All volcanic phenomena are probably the result of a communication, either permanent or transient, between the interior and exterior of the globe." Ten years later, the idea of one general cause for all the varied forms of volcanism has clearly worked itself out in Humboldt's mind, and was thus formulated in the "Kosmos": "In one comprehensive view of nature, these all (namely, the phenomena of volcanism) fuse together into the single idea of the reaction of the interior of our planet against its crust and surface."

While now most geologists admit the validity of this explanation, so far as it goes, the discrepancies of opinion which have arisen in showing how the reaction in question is brought about are very considerable. As long as the theory was only vaguely shadowed forth, and no attempt was made to go into details, but little objection could be offered to it. But when, as facts began to accumulate and more precision of statement and clearness of development were required, in harmony with the progress of modern thought, the difficulties of the case became more and more apparent and the divergencies of opinion greater. Humboldt may be said to have furnished a blank key, which looked, at first, as if it would fit the lock; but every examination has revealed some new ward to which it must be adapted; and different observers have shown themselves very much in doubt as to how it was to be filed to fit the complications which they had discovered, and which combine to make the opening of the lock anything but the simple task which it seemed at first to be.

As time passed on, and the various borings and mining operations all over the world gradually gave absolute certainty to the at first rather hesitatingly received fact of a universal increase of temperature in descending beneath the earth's surface, the views of Humboldt began to be generally received and acquired something like this form: The earth is gradually cooling from a condition of intense heat and igneous fusion. During this cooling an exterior crust or shell has been formed. This crust has, from time to time, been endeavoring to adapt itself to the still shrinking nucleus, and, while so doing, has from time to time yielded to the accumulating tension. The vibration resulting from this sudden yielding has been the principal cause of earthquake shocks, and through the fissures thus formed the molten matter of the interior of the earth has, at various intervals, found its way to the surface in the form of volcanic eruptions and accompanied by all the phenomena of volcanic action. The crust of the earth, in endeavoring to adapt itself to the nucleus, has been in places more or less uplifted or depressed, folded or plicated, thus giving rise to those irregularities of the surface which we call mountains, and which, also, often owe their existence to a direct pouring out of the eruptive material through an elongated fissure, this material then forming the axis of the mountain mass or range.

Those who are familiar with the various geological textbooks in use will recognize that this is the simplest way of expressing the generally adopted theory; but, as will presently be seen, there is the widest variety of opinions and hypotheses when anything like an approach to a detailed statement of the *modus operandi* of the internal forces is attempted.

In the first place, there is considerable diversity of opinion among geologists as to the manner in which the earth has consolidated while cooling. We know that the specific gravity of our planet, as a whole, is about double that of its external crust; and to account for this superior density of the interior, we have to endeavor to combine three conditions, in regard to each of which there is much uncertainty; these are, the nature of the materials of which the portion of the earth beneath the crust is made up, the amount of condensation effected on this by pressure of the superincumbent mass, and the reaction of the internal heat against that pressure. Of course if the interior of our planet consisted chiefly of metallic iron, or any other heavy metal, it would have a higher specific gravity than if silica predominated; but, even if exclusively formed of a material as light as quartz, the earth ought, according to physical laws, to be even much denser than it now is, unless there be some cause acting to diminish the condensing effect of pressure. Different physicists have made various calculations on this subject, the results of which are not very satisfactory in their agreement with each other. But it is certain that if substances continue to have their density increased by pressure in descending towards the earth's centre, in the same ratio as they are found to do at the surface by actual experiment, then we should have to penetrate to but a few hundred miles in depth, to find water as dense as platina, and all other substances similarly compressed. The force which acts against compression, so as to make the earth's density, as a whole, only twice that of its crust, is, in all probability, the expansive action of the internal heat. But we know too little of the properties of bodies at prodigiously high temperatures and under immense pressure, to say positively whether, under such circumstances, the materials of which the earth is made would have a solid or a liquid form; and neither astronomy nor mathematics have been able to give the geologist any valuable assistance in deciding this question. On the contrary, the most eminent authorities in these departments of science have published the most contradictory statements as the results of their investigations in regard to the condition of the interior of our planet. Hence, so far as the astronomical evidence goes, geologists are at liberty to form their own theories on this subject, and some have inclined to the belief that the earth is solid throughout; others stoutly maintain that it consists of a solid nucleus, with a liquid shell near the exterior crust; while the prevailing opinion has been that the solid crust encloses a mass of matter fluid nearly or quite to the centre. This latter idea has been naturally adopted, because we are accustomed to see masses of melted metal or stone cool first on the surface, while the interior, if the mass be large, remains for a long time in a fluid condition. The theory of a fluid interior has also been sustained by considerations connected with the widespread distribution of volcanic orifices, and the vast amount of liquid matter which has been poured forth from them at different epochs. The connection of earthquake shocks with the phases of the moon, adverted to in a previous article, is not without an important bearing on this question. The results attained by all seismologists who have investigated these subjects do appear to indicate that there is a decided action of the moon on the interior, analogous to that which it exerts on the waters of the ocean. The evidence is not as decisive as might be wished, but is too important to be overlooked in the discussion of a subject where precise data are hardly to be obtained or expected. The later researches in physics, however, have shown that there is no such sharp line dividing solids from liquids as was formerly supposed to exist; and all the requirements of geology would be satisfied if it should be admitted that the material constituting the interior of the earth, if not already in a liquid condition, was capable of assuming it when relieved of pressure to a certain extent.

All geologists will agree in this, that the disturbances of the earth's crust, by whatever name we please to call them, whenever acting independently of attraction, or against gravity, are due to internal heat. This, in some way or other, is the cause of all earthquake and volcanic action as well as of mountain-building. If the earth were, as the moon appears to be, entirely cooled down, the heat of the sun and the attraction of the sun and moon would then be the sole dynamic agents in producing geological changes. These changes would be affected chiefly through the action of water. The tidal current, raised by the lunar and solar attraction, the powerful, although slowly acting agencies of rain and rivers, — these would be the principal agents of geological change. But these tend almost exclusively to abrade material from the more elevated, and spread it out again upon the lower regions. Hence, the dynamical agencies at work on the earth's surface, supposing the effects of internal heat to be no longer in action, would be directed to reducing inequalities of height; in short, to levelling down the mountains and filling up the valleys. The character of the changes produced by the internal heat of the earth, on the other hand, is antagonistic to this; not exclusively, but nearly so. The proof of this is visible everywhere: in the mountain ranges and single peaks made of lava and volcanic *débris;* in the ranges having an axis of eruptive rock, which has been thrust up from below and carried the overlying stratified rocks with it; and in many other ways.

It being universally admitted that it is the internal heat of the earth which gives rise to the phenomena of volcanism, we have to inquire in what way the results indicated in our previous articles are brought about. The disturbances of the crust by earthquake shocks present the least difficulty in their explanation. Admitting the gradual cooling of the earth as a whole, we find no difficulty in understanding that this cooling may be unequal and irregular in its progress and distribution. This unequal cooling cannot fail to give rise to unequal tension between different parts of the crust; and as the force accumulates until it overcomes the resistance, so, from time to time, as the yielding takes place, there will be a sudden jar or shock given to the surrounding region, which will be more or less severe, according to the amount of force expended in overcoming the resistance. This sort of operation will go on whether the materials of the earth's crust expand or contract on cooling, or even if they, during a portion of the cooling, contract and afterwards expand. That this is the origin of the great earthquakes is proved conclusively by their character and distribution on the earth's surface. Their association with coast lines, mountain chains in process of upheaval, and recent geological formations, affords sufficient evidence that they are not local phenomena, but linked in the closest manner with those other occurrences which have to do with the building up of mountains and the shaping of the outlines of the continents.

Volcanic phenomena, on the other hand, are vastly more difficult to decipher and refer to their origin, since they are more complicated in every respect, involving chemical as well as mechanical causes and results. To account for all that we know of volcanic rocks is plainly enough a difficult task, since hardly any two eminent authors fully agree in their ideas on this subject. And the larger one's experience and field of observation has been, the more difficult the task of reconciling and correlating all the phenomena has been found to be. Hence, the theories have mostly come from those geologists whose training has been chiefly chemical, and who have looked at nature almost exclusively through the bars of their laboratory windows. Those whose powers of observation have had the widest field for their exercise have had the most vivid perception of the complicated character of the phenomena of volcanic action, and have usually preferred to leave their correlation to others.

The work of Richthofen, the title of which was among those placed at the head of a preceding article on volcanoes, forms an exception to the above remarks, since its author has had an uncommon, in fact almost an unparalleled, range of observation. Having begun with the critical study of the classic volcanic regions of Hungary and Transylvania, he was enabled to carry his researches in an almost unbroken line entirely around the globe, ending with the grandest field anywhere presented to the geologist in this department, the Cordilleras of North America. In several respects this work of Richthofen's,—"The Natural System of the Volcanic Rocks," as it is called,—is one of the greatest importance to the student of dynamical and structural geology. It is the first attempt to go into anything like detail in the investigation of some of the most difficult problems of this branch of the science. That such a work should not meet with immediate attention on the part of the general public was to be expected; that it should undergo criticism was to be desired, by its author, no doubt, as well as others; but, that its positive statements of facts of the highest importance in their bearing on the phenomena of volcanism should be overlooked, and even denied, is something which does not argue well for the comprehensiveness or candor of those thus placing themselves in opposition to the introduction of a "natural system" into that which before had no system at all connected with it. In the course of this article we shall endeavor to bring out some of the more prominent features of Richthofen's great paper, and will, in the proper place, give an idea of some of the criticisms which have been made upon it. But further light must be thrown on the general subject of volcanism, before details can be made intelligible to the general reader.

If we had only the volcanic phenomena of the present day, or active volcanoes, to deal with, the task of unravelling their mysteries would, perhaps, not be one of so great difficulty; but, as soon as we begin to elaborate our materials, and endeavor to correlate the results obtained in the various lines of research, we find ourselves confronted by an immense mass of facts going to show that our present volcanic outbursts are only the last remains, or dying out, of a series of geological events, the scale of which was formerly much grander than it now is. We find, without going back to any great distance in geological history, that there was a time when, instead of being poured forth from scattered isolated orifices, the eruptive material found its way to the surface through linear rents, or fissures, which often must have extended for hundreds, or, perhaps, even thousands of miles. We find the material which has thus been poured forth occupying the surface in vast sheets, often lying in nearly horizontal beds, and covering an area of many thousand square miles. We find vast chains of mountains almost wholly built up of volcanic rock, and we are able, on careful examination, to recognize the fact that these masses have not been brought to the surface in lines radiating from a centre, that centre being what we call a volcano; but along a linear axis, in the form of "massive eruptions," as they are called by Richthofen, who has been the first person to clearly distinguish between the two kinds of eruptive action, and to give a name to *massive*, as distinguished from ordinary *volcanic*, eruptions. The necessity of keeping in mind the difference between volcanic materials erupted from a crateriform opening and those poured forth from a linear fissure was made evident by Professor Dana more than twenty years ago, in his admirable generalizations on the geological results of the earth's contraction and the formation of continents.* This idea was also clearly present in the mind of Humboldt at the time of the publication of the first volume of his Kosmos, and Richthofen has in fact carried out some of the suggestions then made by him with regard to the necessity of investigation, by competent lithologists, of the different portions of volcanic ranges which have been piled upon each other at successive epochs and in various ways. And yet we find Mr. Scrope, the veteran author of a much-quoted general work on volcanoes and of the classic description of Central France, denouncing in the most violent language those geologists who think they see any difference in the manner in which volcanic rocks are now and have formerly been erupted.† This fact alone will answer as a sufficient demonstration of the difficulties which the study of volcanic rocks presents, and of the disagreement in theoretical views among geologists, as soon as they begin to enter into details with regard to the mode of volcanic action. ‡

The distinction between massive and volcanic eruptions has been excellently illustrated by Richthofen, as follows: "It is well known that small cones are frequently met with on the slopes of larger volcanoes. If they occur in large number, as on Mount Etna, they are usually situated in lines which radiate from the crater. Each of them is built up of layers of scoria and ashes sloping away from the centre, where a crater is immersed, and such cones will occasionally emit currents of lava, and be in fact the repetition on a small scale of the mother volcano. Just as these parasitic volcanoes have their roots in the glowing lava, volcanoes in general must, as is demonstrated by their mode of occurrence, be considered as parasites on certain subterranean portions of the material of massive eruptions, which still possess a high temperature and are kept in a liquid state by the molecular combination with water which finds access to them."

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* See "Geology of the Exploring Expedition," and a review of the same in the North American Review, Vol. LXXIV. p. 301, by the author of this article; also American Journal of Science (2) ii. 335 ; iii. 94, 176, 381 ; iv. 88; vii. 379.

† See Scrope in Geological Magazine, Vol. VI. p. 512.

‡ Mr. Scrope goes still further in his misconception and misrepresentation of Richthofen's views. He says, "the value of M. Richthofen's " — to an Englishman all foreigners, whether German barons or otherwise, are "M.s" — "Natural System of Volcanic Rocks, as a contribution to the science of geology, may be estimated from the fact that he denies the occurrence of any volcanic rocks in the series of geological formations preceding the tertiary era." The simple fact being that "M. Richthofen " has, for convenience, and following the large majority of authors, chosen to designate the eruptive rocks of the tertiary era as "volcanic," and those of preceding epochs in another manner.

Richthofen then goes on to show that this mode of origin of volcanoes is only a repetition on a smaller scale of the manner in which massive eruptions themselves originated. Volcanoes bear the same relation to massive eruptions which the latter do to the material forming the primeval interior of the globe. What is this material, and what its relation to the rocks which we call volcanic? These are questions which we have to endeavor to answer.

We must first try to ascertain what volcanic rocks really are. All are familiar with the distinction between igneous and sedimentary rocks, that is, between rocks which have once been in a molten state and which have come to the surface or been deposited through the action of igneous causes, and those which have been deposited by water. Most persons also understand the term " metamorphic " as used by geologists, meaning that the rocks embraced under that term are not what they once were; that they have suffered certain chemical changes since their deposition, in the course of which the mass has undergone a rearrangement of its particles, so as to have assumed a crystalline texture, separate and distinct minerals segregating out of what was before an amorphous mass in which no particular crystallized minerals could be discerned. Hence, the metamorphic rocks are often called the crystalline rocks. This distinction of rocks into igneous, sedimentary, and metamorphic is, of course, more or less arbitrary. For instance, showers of pumice-stone and ashes may be, and often have been, thrown from a volcano, and the eruptive material falling into water will then have assumed a stratified condition as it sank to the bottom, just as any mud or sand would do. The strata thus formed, having been raised above the water, or while still beneath it, may have undergone chemical changes, or become metamorphic in character, so that the mass now partakes of the character of all three classes.

The formation of sedimentary rocks implies evidently the pre-existence of some other rock on the earth's surface as the source of the material of which they are formed. Igneous rocks, on the other hand, must have come from beneath the surface, where they have existed from all time, as we may suppose. Believing in common with almost all geologists, that the earth has cooled from a condition of intense ignition, we of course recognize the fact that there was a time when all existing rocks were of igneous formation, — the consolidated crust of the earth was an igneous formation. All the material of the sedimentary rocks must have come from this source; but it may have gone through several cycles of change. Igneous rock has been ground to powder and deposited in water; this material has been again broken up and again deposited; and no one can say that this process may not in some regions have been repeated a good many times.

It becomes important, then, that some criterion should be established by which the eruptive rocks may be distinguished from the other classes. That knowledge of this kind is needed will be apparent when we consider that the conclusions we have to draw in regard to the dynamical agencies employed in getting the rocks into their present condition and position must depend to a large extent on the origin of those rocks. For instance, if we consider a certain crystalline mass forming the axis of a chain of mountains as an eruptive rock, our conclusions in regard to the structure of that chain will be very different from what they would be if we considered the same material as simply a sedimentary rock which has assumed a crystalline texture from the effects of metamorphic action.

Here, then, we come upon another of the difficulties or discrepancies of opinion among geologists, who, starting from the theory of the original igneous fluidity of the earth, begin almost at once to diverge in their paths towards the goal they wish to attain, which is nothing more nor less than the solution of the great problems of dynamical geology. With regard to the rocks which have come to the surface from beneath during the tertiary epoch, and which we call volcanic, there is but little difference of opinion. We see them now issuing from volcanic vents, and to those products of massive eruptions which precisely resemble in texture and composition the ejections of existing volcanoes, we do not hesitate to assign a similar origin. There are, however, many varieties of rocks, occurring in great masses, and belonging to the older epochs, which were formerly almost universally considered to be eruptive, and in regard to the real nature of which there is now considerable discussion among geologists. These are the rocks of the granitic and porphyritic families. Granite and syenite are the predominating types of the granitic, and quartzose porphyry of the porphyritic family. These are the ancient eruptive, or ancient volcanic, rocks in the opinion of many; while others look upon them as having been originally sedimentary, and as having assumed their present crystalline texture through the influence of chemical changes, — in short, they are not eruptive, but metamorphic. By those who adopt the metamorphic origin of granite and porphyry the argillaceous slates are supposed to have furnished the material for the first-named of these, and the sandstones for the other. If this view were correct, we should, as advocates of the gradual consolidation of the globe from a condition of igneous fusion, be placed in a difficult position, for we should have to show how it was that, in a gradually cooling globe, eruptive material was not brought to the surface in large quantity until the latest epochs, when, as would naturally be supposed, the crust of the earth having become greatly thickened and the interior sensibly cooled, eruptive action would have diminished instead of having increased. To avoid this difficulty, some of the chemical geologists — and of those who maintain the metamorphic origin of granite such are indeed the only consistent ones — deny altogether the existence of any primeval eruptive rock. To them all visible rocks are either sedimentary, or they have been such; and what are ordinarily called volcanic and eruptive masses are nothing but sedimentary deposits which have been softened or liquefied by the internal heat, and thus enabled to flow as lava. The idea of these geologists seems to be, that the series of changes has been going on so long on the earth's surface that no portion of the original crust can, by any possibility, remain visible. It is a pushing to its extremest limits of the favorite theory of Lyell, that no traces of a beginning are to be found; or, at least, that the beginning is to be put back as far as possible, and that all geological phenomena are to be interpreted with that one idea in view, the result being that some facts have been extraordinarily distorted and others overlooked, for the purpose of making things pleasant in that direction. Such persons as wish to make it appear that no proofs of a beginning can be found in geological facts must go still further, and deny that the earth has ever been in a condition of igneous fluidity, from which it has been gradually cooling through all the geological ages. They are trying to pull out the corner-stone from under the fabric of the science.

It can be clearly shown, as it seems to us, not only that the volcanic rocks are not softened or metamorphosed sedimentary materials, but that the same is true of the rocks of the granitic and porphyritic families; these are, in fact, samples of the primeval crust of the earth, such as it was before any sedimentary rocks had been formed. In order to get at some of the proofs of this, it will be necessary to consider, for a moment, the mineralogical composition of the different families of the eruptive rocks; these are all almost exclusively aggregates of silicious minerals, including among them silica itself or quartz. Several different kinds of feldspars; hornblende and augite, two very closely allied minerals; quartz; different varieties of mica; magnetic iron: — these are the substances of which all eruptive rocks, including granite, porphyry, and lava, are almost exclusively made up. Quite a number of other minerals do indeed occur in them, but almost always in very subordinate quantity. The close resemblance in external appearance and actual composition between eruptive rocks from different parts of the world is, indeed, a surprising fact. But it is more surprising still to find that, as shown by the researches of the great chemist Bunsen, the materials of which these rocks are made up are combined in certain definite proportions; so that if we determine by chemical analysis the quantity of any one of the ingredients of which a specimen is composed, we can by mathematical calculation arrive very nearly at the amount of each of the others. The "law of Bunsen," as it is called, is of the greatest possible importance in its bearing on the question of the origin of the eruptive rocks. It must be evident to all that this law could not be true if the rocks to which it applies were of metamorphic origin. If that were the case, and they were really derived from the sedimentary deposits, they could not, by any possibility, fail to have the same varying composition which these sediments themselves have, and which can by no means be brought under Bunsen's law.

There is also another fact which has a most important bearing in this connection. It is this: that the order of succession of the volcanic rocks has been the same all over the world; they have not come to the surface in different regions in an indiscriminate manner, but in a certain sequence, or chronological order. This extremely important fact was first brought out by Richthofen, who, by means of his specially good opportunities for the study of this class of rocks, was enabled to recognize and clearly lay down this order of succession, and demonstrate its correctness by examples collected all over the globe. The chronological order of succession, as well as the law of composition of the volcanic rocks, are clearly opposed to the idea that these are the results of the metamorphism of the sedimentary beds. The material of which these volcanic ejections are made up must have come from beneath the shell of sedimentary deposits; and as it everywhere came from beneath this shell in a certain chronological order, so it must ever have previously existed there in the same order. If basalt has always been erupted after andesitic lava, then basalt must have everywhere formed a shell of material underlying andesite in the earth's interior; that is to say, the mass of the earth beneath the shell of sediments is formed, for a certain distance down, of layers of somewhat different material, and these layers are arranged in a similar order all over the world. What is this order? Is it one in which we can find something logical, something which seems to be connected with the nature of the materials themselves? To this question the answer is, in a general way, affirmative; but it must be admitted that the processes of volcanism are so complicated that we cannot expect an agreement in all minute details, but only in the general order of events, looking at them in the largest way. It will not do to study up the exceptions to the general rule and make them our standards, as we are likely to do if we confine our observations to any one locality. We are rather to try and get the general principles established, and then endeavor to account for the apparent exceptions in a manner which will be in harmony with the general well-established series of facts. Thus, if it can be shown that over nine tenths of the globe the order of succession of the volcanic rocks is one and the same, then let this fact first be thoroughly demonstrated, and afterwards let the exceptional cases in the remaining tenth be investigated, each on its own merits, in its necessary subordination to the general law.

In something like this spirit the investigations of Richthofen, in regard to the order of succession of the volcanic rocks, must be received. It is not claimed that he has clearly made out their precise sequence in all localities and for all geological epochs; but that there is a certain order to which they have conformed, over a large portion of the earth, and especially during the tertiary period, can no longer be doubted; while it seems probable that the exceptions which do occur will be found to be of comparatively slight importance, and that all geologists will have to admit the value of these investigations in their bearing on the difficult questions to which they are applicable.

It certainly seems clear enough that, on the whole, the order in which the volcanic rocks have appeared is one which we ought to have expected, if the theory of a gradually cooling globe be true. The more silicious and, of course, the lighter kinds were the first to be emitted from the interior, and these have been succeeded by denser or more basic ones. This statement is not so peculiarly applicable to the volcanic as it is to all eruptive rocks, beginning with the earliest epochs and including the granitic family. From this point of view it is evident that quartzose and the more highly silicious rocks prevailed almost exclusively during the earlier periods, and that they have gradually become replaced by the more basic. Granite and syenite were once the predominating eruptive rocks; in the latest geological ages basalt and andesite have been.

As the development of the earth's history has gone on, the regions of igneous action have become more and more localized, and we have now only eruptive materials issuing from craters or isolated orifices; the days of massive eruptions, or such as took place from fissures of great length, have passed. This is as we should expect; for, although there are some who follow the school of Lyell so far as to reject everything which looks like more violent action of any kind in the past than at present, yet, unless we admit that igneous forces were more actively at work and more generally disseminated than they now are, we must give up altogether the hypothesis of a gradually cooling globe; and, with this theory gone, we are entirely afloat,— absolutely destitute of any guide through the mazes of structural geology. We must admit that the crust has been constantly thickening, while the cooling has been going on; and if this has been the case, the facility with which the molten matter in the interior has found its way to the surface must have been constantly diminishing.

There is a point, in this connection, to which our attention must be for a moment turned. There is a difference between the granitic and the ordinary volcanic rocks, as regards the method in which they have come up from beneath, dependent on their position as portions of the exterior shell of the earth, in consequence of which the former have more of an intrusive, and the latter rather an eruptive character. Forming, as it did, the original surface or uppermost layer, granite has often been raised in ridges, before any sedimentary rocks existed, through which it must otherwise have been obliged to force its way. There being no resistance from the weight of overlying materials to be overcome, this rock could assume a higher position without having to wait for tension to accumulate so as to form fissures, as has been the case with the more recent eruptive masses, which have had to find or make in some manner a passage through a considerable thickness of the consolidated crust, before they could appear upon the surface.

The real character of granite and the granitic rocks has been much discussed of late among chemists and geologists, the former adopting usually the metamorphic theory of its origin, the latter, on the other hand, almost all taking the other side. The field geologist sees these rocks occupying a position which it seems impossible that they should have, unless they have been forced upward when in a liquid or plastic condition, and he observes also a great many facts which preclude the idea that this liquidity or plasticity has originated through metamorphic action on sedimentary materials. And in a question of this kind, at present the geological facts must be allowed a greater weight than the chemical, since chemistry has thus far proved to be rather a blind guide to those endeavoring to unriddle the mysterious reactions of the primeval earth. That the peculiar texture of granite, as compared with that of the volcanic rocks proper, does present a difficulty, there is no doubt; but if we consider that this rock, forming as it did the exterior crust, must have been in much closer proximity to the ocean than were the underlying masses, we shall have no difficulty in understanding that a larger amount of water and a lower temperature were conditions which exercised a powerful influence in determining its texture.

There can be no doubt, then, that the seat of volcanic action has gradually receded from the exterior towards the centre, and that in so receding it has descended into regions of denser material, and that these regions have been reached in the same order in different parts of the world, showing that the arrangement of the materials of the crust is everywhere strikingly similar.

We have an important and difficult question to answer in endeavoring to ascertain the nature of the force which brings the material of the molten interior to the surface. This is a subject which has been passed over without discussion by some writers, while others have given it a measure of consideration, usually making it evident by their treatment of it that they felt its difficulties. It used formerly to be supposed that the opening of a fissure in the earth's crust would necessarily cause the molten material below to issue forth without further cause. The insufficiency of this as a reason has been felt by the later writers; but of those discussing the subject hardly any two have been agreed in their views. Sometimes the differences of opinions thus disclosed are not radical; but usually they are, and in a good many instances we find authors diametrically opposed to each other. In one respect there is a fair amount of agreement among the theorizers on volcanic phenomena. Almost all consider the access of water as essential, in some way or other, to the emission of lava. But in regard to the *modus operandi* of the water and the manner in which it is to find its way down to the volcanic focus, most authors are found to preserve a discreet silence. Mr. David Forbes, whose lectures and writings on these subjects have been much circulated of late in the English magazines, says that all which is required to account for the phenomena of volcanic action is "the assumption that water from the sea should, *by some means or other*, find its way down into the reservoir of molten matter beneath the surface"; what the means are by which the water is to gain access to the interior are not given, nor is the mode in which the water acts after it has reached the depths anywhere explained. Scrope, who was among the first of modern authors to advocate the necessity of water as an agent in volcanic eruptions, solves the difficulty in a most curious manner, namely, by supposing the water to be already present in the material which is to issue forth as lava, and only waiting to be vaporized whenever a transfer of heat into the region takes place. To use the words of that author, "It is now generally recognized that the power which forces up lava from a depth of miles, through narrow and crooked fissures broken across the solid crust of the globe is no other than steam, developed in the interior of the lava by vaporization of water intimately disseminated throughout its substance." Professor Phillips, one of the most cautious of the English writers on geology, in his latest work on Vesuvius, quoted in a previous article, incidentally alludes to water as a cause of "volcanic excitement," as he terms it, but goes no further in that direction.

The eminent chemical geologist, Bischof, is the only author who has gone into anything like an elaborate discussion of the manner in which water might gain access to the molten interior and act as a motive-power in the ejection of the lava. He perceives some of the difficulties in the way of the adoption of this idea, and endeavors to remove them. It seems pretty clear that steam at its maximum elastic force would not have power enough to raise a column of lava from the region from which it is supposed to come up to the summit of even a moderately high volcano. This difficulty Bischof gets over by supposing that the column of lava has lengths of steam included in it, like the bubbles of air in a barometer tube. This explanation is also adopted by Lyell, who follows Bischof closely in all that relates to the theory of volcanic action. This hypothesis, moreover, clearly involves another difficulty, which is this: that two columns, one of water and the other of lava, must be in communication with the molten mass of the interior of the earth, and yet that the elastic force of the steam generated by that water shall throw out, not the water itself, but the lava. It is believed by some physicists that it may be possible for water to pass through minute fissures, through which it cannot return when converted into steam, although this has not yet been clearly demonstrated. But, even admitting this, it does not appear how it is that the force of the steam is used to lift up the column of lava to a height of ten, fifteen, or even twenty thousand feet above the level at which the water enters, rather than to blow out the fissured and necessarily much weakened thinner portion of the crust through which the water has found its way. This objection is an insurmountable one, in our judgment; and, indeed, the assumption that steam is the *primum mobile* in all volcanic eruptions is one beset with difficulties. No theory of volcanoes can be adopted that will not account for the phenomena of massive eruptions as well as for ejections from crateriform orifices, and this the water theory is obviously incompetent to do. That water comes into play in volcanic eruptions there can be little doubt; but this is in the later stages of the process, when cinders and ashy materials are chiefly ejected. And it is by no means certain that the rain may not be quite as competent as the sea to supply the necessary water. Much stress has been laid on the fact that most volcanoes are near the sea or on islands, as going to prove that eruptive action cannot take place without the presence of sea-water. But it must be recollected that this nearness is, in many cases, only comparative, with reference to the total breadth of the continent, and not absolute. Thus the volcanoes of the South American Andes are, in many instances, two hundred to three hundred miles from the sea, which is certainly a long distance for action to be transmitted laterally through the intervening rock. Besides, there are not a few regions where, within a recent geological period, if not during the present epoch, volcanic action has taken place on a large scale, at a great distance from the sea, at a high altitude above it, and also far from any inland waters of magnitude, which might be supposed to answer instead of the ocean as feeders to the volcanic excitement. We need only instance, in this connection, the line of volcanoes which extends across our continent through Northern Arizona and New Mexico, of which Mount San Francisco and Mount Taylor are the dominating summits.

Everything indicates that we cannot separate the agencies which give rise to the formation of mountain chains from those which are energetic in volcanic eruptions. Whatever cause is capable of folding the crust of the earth into ridges, or thrusting a portion of it up above the adjacent parts, is also competent, if carried a little further, to produce a fissure, and through this the underlying material, whether it be in a fluid, plastic, or viscous condition, may be forced, by the pressure arising from the subsidence of that portion of the crust which borders it on one side or the other.

We have, therefore, to go back another step and endeavor to ascertain what the forces are which have been active in producing those ridges of the earth's surface which we call mountains. A mountain may result either from a positive elevation of the mass, or from depression of the adjacent region. We leave out of view here those elevations which have their origin simply in denudation or erosion by water of the surrounding surface, for these are easily understood and comparatively unimportant. It is true that we have absolutely no means of ascertaining how much, in the past geological ages, of the elevation of our mountain chains is due to actual upheaval or increase of distance from the centre of the earth, and how much to depression of other portions of the surface. We are accustomed to refer all elevations to the level of the sea as a zero, but we have no reason to suppose that this level has itself been invariable ; that is to say, it cannot be taken for granted that the distance from the centre of the earth to the sea-level at any particular point on the earth's surface has always remained the same. On the contrary, there is abundant evidence that the sea-basins have deepened since the earlier geological periods ; but of the extent to which the sinking of the sea-level which would thus be produced has been compensated by an increase of the area of the land, we can only form the crudest conjecture. We do not yet know the depth of the deepest portions of the ocean, or where they are situated.

Looking at the surface of the earth simply with reference to continental and oceanic areas, we have reason to believe that the differences of level between them are the result of depression rather than of elevation. The masses which now form the continents have been left where they were, while the ocean beds have sunk and allowed the water to retire from the more elevated portions. This follows, indeed, necessarily, from the nature of the assumed cause of differences of elevation, namely, the shrinkage of the interior, and the endeavors of the crust to adapt itself to the diminished nucleus. If we conceive that the globe, as a whole, shrinks somewhat unevenly, and it is hardly possible to conceive that it should be otherwise, since neither the composition of the cooling body nor its rate of parting with its heat would be likely to be entirely uniform in all its parts, then the region in which positive elevations would be likely to take place would be the borders of the most rapidly shrinking area, or where it joins on to the portion which remains comparatively stationary. These more rapidly shrinking areas would, of course, be the ocean beds, and the stationary area the continental masses, while the edges of the continents would be the region of positive uplift or of mountain formation. This is the basis of Professor Dana's theory of the formation of continents, as set forth by him in the " Geology of the Exploring Expedition " and elsewhere,* and of which a synopsis was given by us in this Review some twenty years ago. The investigations of geologists have, since that time, given additional value and lustre to these lofty generalizations of Professor Dana's, in the opinion of the writer of this article, although it must be admitted that they have not met with general adoption. Other theories have been suggested and discussed, but without any very definite conclusions having been arrived it; at all events, the conclusions reached have rarely been satisfactory to others than their authors. A great mass of material has been gathered bearing on the structure of mountain chains, or, at least, capable of being made available in that direction; but little has been accomplished in the way of applying this information to the working out of any theory of mountain building. What theories have been suggested have been of the vaguest kind, and, in some instances, facts have been entirely ignored in supporting them.

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* See references on page 245.

While believing, with Professor Dana, that mountain-building is, to a large extent at least, the result of an antagonism between subsiding and stationary masses of the earth's crust, we are fully aware this is a somewhat vague way of stating the case, and that a more detailed account of the agencies at work in this operation, and of the methods in which they act, is extremely desirable. But when we come to examine what is known of the detailed structure of the great mountain chains of the world, we find that, in spite of all that geologists have done, our information is exceedingly defective. In the chain of the Alps it is true that we have a great many local sections in the works of Gümbel, Favre, Studer, and especially of the geologists of the Austrian official survey, the Reichsanstalt. But how deficient are our generalized sections across the entire chain! Indeed, there is not one on a large scale from which an idea of the structure of the mass, as a whole, can be obtained. And if this be true for the Alps, how much more is it likely to be so for the great chains of Asia and of America, which, in comparison with the much visited and studied European mountain masses, are almost unknown. Indeed, it is only quite recently that the subdivisions of our own Cordilleras, grand as they are, began to be indicated on our maps or even to receive names. And not even so far as that has our knowledge of the Asiatic chains of mountains reached. Of that vast region north of the main Himalayan range, on which are piled the masses of the Kün-Lün, the Karakorum, and others, we know as yet almost nothing, so far as geological structure is concerned.

Even the sections which the India survey gives of the middle and lower Himalayan ranges are on a small scale and difficult to unriddle. Generalizations in regard to mountain structure at the present time, which profess to go into some detail, must, therefore, be drawn with much caution, and taken rather as indicating the direction in which future and much-needed work may be accomplished, and not as based on anything completed.

Of all mountain forms, the simplest are those which result from denudation. Masses of rock are often left standing, isolated from each other by the removal of the adjacent material through the action of water; and these masses, where the erosion has been extensive and long continued and in suitable strata, are occasionally so large as properly to be called mountains. There are fine examples of the forms resulting from erosion in our Rocky Mountain region and farther west. But erosion on a large scale cannot take place without continental elevation. There must be a rapid inclination of the surface towards the sea to admit of portions of the surface being deeply cut into by the streams which traverse it. Hence the formation of mountains by erosion is rather to be regarded as a secondary operation, and as a sort of carving of an already elevated mass into detached portions which may then bear the name of mountains, which, previous to the erosion, the whole would have been called simply a plateau. The Book Mountains in Colorado are admirable instances, on a grand scale, of this mode of formation.

The next most simple form of mountain building is that in which masses of rock — and it is chiefly the sedimentary formations which are thus acted on — are broken across and tilted up at an angle, from an unequal subsidence of the fractured portions; something as we see happening in the ice covering the surface of a lake when it has been broken up by the waves and then frozen together again, the different pieces being inclined to each other at slight angles, instead of lying all in one plane as before. Such mountains are not usually developed on a large scale, for in almost every case, if there is a fissure formed, there is an outpouring of eruptive material.

If, on the other hand, the group or series of strata, instead of being broken across and tilted, are gradually bent, then a ridge or protuberance of the surface will be formed, and it will have, of course, various degrees of curvature. A series of such ridges will alternate with relatively depressed regions or valleys, the whole forming a system of foldings which are very likely to be parallel or nearly so, because parallelism in this case merely means a persistence of the bending agencies in one direction. Such a system of parallel ridges or folds may be seen in the Appalachians and the Jura, two perfectly typical regions in this respect. But these may not, by any means, be taken as representatives of all mountain chains, as has been done by Hall and H. D. Rogers. On the contrary, they are only chains of the second or third order of magnitude, so far as elevation is concerned, and in many respects exceptional. They are, so far as we know, the only systems of mountains, having great geographical development, in which there has been no emission of eruptive material from below and no extensive metamorphism.

It seems to be clearly indicated by the results of geological investigations, that the great mountain chains of the world have been blocked out — if the use of such a phrase may be permitted — from the earlier geological times, and often from the earliest. Their structure shows most distinctly that their development has been a gradual one. But it was not always the case that this development was continued down to the latest period. On the contrary, many chains have ceased to grow after attaining a certain elevation ; and, having ceased to be influenced by forces acting from beneath, they have ever since been subjected to those erosive agencies which constantly tend to plane down the inequalities of the surface. Hence, the highest chains contain the most recent geological formations. The Himalaya, the Alps, the Andes, the Cordilleras, — these are the great chains of the world, and these are all made up, in part at least, of the newest formations. The Ural, the Scandinavian Mountains, the Appalachians, the Brazilian ranges, — these are examples of mountain chains which have ceased to grow at a comparatively early geological period, and within whose masses no modern rocks can be found.

The results of modern investigations, especially in the Andes and Cordilleras, are diametrically opposed to the theories of Elie de Beaumont, on which he has spent so much labor, and which he has built up with such care and such an outlay of mathematical calculations. According to the views of this eminent French geologist, the earth in cooling and contracting has developed its mountain ranges along lines which are parts of great circles drawn about the globe in a network of curves developed symmetrically from the points where a solid with regular pentagonal faces included within the earth would touch its surface. It is also a part of De Beaumont's system, that mountain chains having the same direction must be of the same geological age; so that law, order, and crystalline harmony would seem to be clearly established in what would otherwise seem almost a chaos of facts, if these theories should bear the test of close examinations, and found to be applicable all over the globe. So desirable was this, that it is no wonder that many geologists were glad to become converts to these views. One by one they have dropped off, however; and few excepting Frenchmen are now found upholding the theory of the pentagonal network. Many years of labor among mountains of the first rank have convinced us that the real facts are almost exactly in opposition to Elie de Beaumont's views. Instead of its being true that identity of direction in mountain chains implies identity of geological age, one might almost say that just the opposite is true. Certain it is, that the great mountain chains are made up of distinct portions, which have similar directions and very different geological ages. Thus, in the Andes and Cordilleras, we have one grand system of mountains made up of an aggregation of many different parts, each having approximately the same direction, and each of these parts or sections being the result of a series of geological changes which have been going on through all the epochs, from the earliest to the latest.

Take, for instance, the widest portion of the whole belt of mountains which forms the western side of the American continent, or that between the thirty-sixth and fortieth parallels of north latitude. We have here a mass of ranges fully a thousand miles in width, having a certain unity which cannot be disputed, and yet made up of parts which have been growing on to each other ever since the azoic period. For, even at that earliest geological epoch, the chain of the Rocky Mountains was marked out, and each successive period, down even to the very latest, has seen some additions made to the mass.

In all great and complicated chains of mountains, almost without exception, we find eruptive rocks forming a portion of the mass; these may be either ancient or modern, or both together. Great chains almost invariably are made up, to a large extent, of granitic rocks; usually granite itself forms the bulk of the mass. Volcanic overflows may or may not occur; different chains differ very much in this respect. The granite usually forms the central and higher portion of a great chain; it is a remarkable exception when this is not the case. In the Alps, while the bulk of the central masses are of a granitic character, there are a few very lofty and almost isolated points or even large domes made up of sedimentary materials, as, for instance, the Matterhorn, and some of the very highest portions of the Bernese Oberland. In the Himalayas the main portions of the higher ranges seem to be granite, but data are extremely deficient for those regions. Eruptive rocks, both of the granitic and volcanic types, are abundantly but very unequally disseminated through the great ranges which make up the Pacific edge of North and South America. The Andes are very largely made up of volcanic materials piled on each other to an immense height; these appear to predominate over the granitic; but different portions of the chain are very unequally situated in this respect. The same is true with regard to the North American Cordilleras; here, vast masses of granitic rocks forming exclusively all the more elevated ranges; there, volcanic materials covering up all the others, and far exceeding them in quantity.

When the study of orography was in its infancy, it was thought that the typical form of mountain ranges was that of a mass or wedge of granite thrust up from beneath and carrying with it the sedimentary rocks through which it had made its way, which would then be symmetrically disposed upon the central mass, the stratified beds dipping each way from it, and forming what geologists call an anticlinal axis. It was found, after more accurate observations began to be made than were customary in the early days of geology, that the structure of most of the great chains was by no means so simple as this, and, consequently, some hastened to conclude and to state that no such thing had ever occurred at all. Some even went to such an extreme in the opposite direction as to maintain that all mountains had a structure exactly the reverse of the anticlinal, namely, synclinal. Of this theory more presently; it must be considered in connection with that which makes granite and all the granitic rocks to be of sedimentary origin, and not eruptive, but metamorphic.

Believing, as we do, that granite or some rocks of the granitic family formed the original exterior crust of the earth, it is not difficult for us to understand that these must necessarily form the core of most mountain chains, and that especially it must predominate in those which reached their full development during the earlier geological ages. When the ridging or wrinkling of the crust began to take place, granite, being the uppermost layer, was raised into the highest position, and might be elevated to almost any amount, provided the base on which the protuberance was raised was broad enough. Circumstances, the exact nature of which it would not, in the present state of our knowledge, be easy to state in detail, have differently influenced the different ranges in regard to the point whether the granite crust should be entirely broken through and the underlying more basic rocks be brought to the surface. In the Andes and Cordilleras, everywhere the eruption of the granite has been followed, at some stage of the mountain-building process, by the outpouring of volcanic rocks, beginning with propylite and andesite and ending with basalt. We know too little of the structure of the great South American chain as yet; but it is certain that modern volcanic rocks form a large portion of it, and that granite lies at the bottom of the whole, although subordinate in quantity, at least through considerable portions of the chain. In North America the granite predominates, on the other hand, and the volcanic, although crowning the range in many places, is, on the whole, much inferior in bulk to the more ancient eruptive masses. This relation is changed, however, as we go north, and in Oregon basaltic lava covers almost the whole of the Cascade Range, and has flowed far and wide over the adjacent country. Striking as is the predominance of volcanic rocks in the mountain ranges which encircle the Pacific, it is still more extraordinary to find them almost wholly absent in the High Alps, and in the Himalayas so far as yet ascertained, while abundantly exhibited both north and south of these ranges. Thus the vast lava plains of the Dekkan lie to the south of the Himalayas, while to the north extensive volcanic formations are also reported; but so little is accurately known of that region, that it is hardly possible to say whether there are any traces of active volcanism there. The volcanic formations of Europe lie to the north and south of the Alps, at a considerable distance, as any one may see by consulting a geological map of that country. The best solution which can be offered for this problem of the unequal distribution of volcanic rocks on the two opposite continental masses is, that in Europe-Asia the thickness of the granitic crust was greater than on the American side, so that the underlying volcanic masses could not find their way to the surface through the uplifted protuberance, but only at its edges, where tension was great and the thickness of the granitic layer less than towards the centre of the uplift. That this may have been the case is indicated by the much greater extent of the land mass of the continent of Europe-Asia, the greater absolute height, and the vastly greater breadth of the ranges taken as a whole. When these die out, then the volcanic rocks come in, as to the south of the Caucasus and in the space between that chain and the western extremity of the Himalayan ranges. It is not without a meaning in this connection that, as it appears, the phenomena of absolute elevation have been continued up to a later geological period in the chains bordering the Pacific than in that region which includes the Alps and the Himalayas.

The mechanism by means of which simple upheavals, uplifts, or downthrows of portions of the stratified shell of the globe are accomplished is not difficult to be comprehended. But, to explain the origin of so complicated a series of folds as that exhibited by the Jura and the Appalachians, where there is no central axis of crystalline or eruptive rock, is a more difficult task. Among the theories proposed to that end, that of Professor H. D. Rogers is the wildest and most fantastic. According to this, it was the pulsation of earthquake waves through the molten interior of the earth which laid the superficial crust in plaits. As this idea has never met with acceptance on the part of any sober-minded worker in geology, it need only be alluded to here. If it had not been elaborated with so much care and brought forward on so many occasions by its author, it would have seemed as if rather intended to be classed with that half-playful hint of Sir John Herschel's, that the heat of the sun is kept up by monstrous organized existences, whose dim outlines are revealed to us in the willow-leaf structure of the surface of our "ruler, fire, light, and life," as Mr. Proctor calls the centre of our planetary system. There is nothing about Professor Rogers's theory which will bear the test of examination. It has not the slightest adaptation to chains which are unlike the Appalachians in structure, and, as already stated, this range and the Jura are quite exceptional in character. From it we get no clue as to how the waves originated; how they were propagated from one side only, as would be required to meet the case of the structure of the Appalachians; how the strata, instead of being shattered in pieces by the rapid pulsations of the internal fluid, were gradually bent in such a manner as could only have been accomplished by very long-continued action; how the corrugated crust was held in place after the passage of the wave. In fact, from whatever side we examine this theory, it presents nothing but difficulties, of which only a few have here been suggested.

Another theory of mountain formation, which was first intended to be applied to the Appalachian chain, but which has since been stretched to fit all mountain ranges, is that of Professor James Hall, which has also been supported by Mr. Sterry Hunt, and by Mr. Vose, in a work entitled "Orographic Geology." This last-named gentleman, who prints "civil engineer" after his name on the title-page of his work, as if he feared that, by some possibility, he should be taken for a geologist, has adopted Mr. Hall's theories *in toto*, which he could more easily do, since he was not hampered by any of those difficulties which have their origin in a personal acquaintance with the subject.

Professor Hall's theory is rather an application or enlargement of the views of Herschel and Babbage in regard to the manner in which the internal heat of the earth may be supposed to affect regions where deposition or denudation of the strata are taking place. As it is known from observation that the isogeothermal lines, as they are called, that is, the lines of equal temperature beneath the surface of the earth, rise and fall with the elevations and depressions of the surface, so that the underground isothermal surfaces correspond in contour with the external surface. This being the case, if over a certain region there is a deposition of sediment going on, then there must be a rising of the temperature beneath while the isogeothermals are adapting themselves to the new surface. Exactly the opposite will take place in a region from which the material is being abraded. Thus, as erosion and deposition of sediments are always going on, there are always changes of temperature taking place over the earth's surface, by which expansion and contraction of the rocks are effected. This is presumed by Babbage to be an agency of the first importance in producing geological changes, and Herschel also insists upon the increase and relief of pressure in different regions, according as material is deposited or abraded, as also necessarily being one of the mightiest of the causes by which changes in the configuration of the surface are brought about.

These views have been applied by Professor Hall in this way. Deposition of sedimentary materials can only take place continuously and for a long time in a region which is subsiding, as all geologists will readily admit, since detritus must be carried from a higher to a lower region, and if that less elevated area does not subside it will soon be filled up with sediment. Subsidence, however, according to Professor Hall, involves plication or folding of the strata, which must take place when large thicknesses of material are pressed downwards. To use the Professor's own words: "By this process of subsidence, as the lower side becomes gradually curved, there must follow, as a consequence, rents and fractures upon that side; or the diminished width of surface above, caused by this curving below, will produce wrinkles and foldings of the strata." Further on he adds: "But the folding of the strata seems to me a very natural and inevitable consequence of the process of subsidence." The results are, according to this theory, that mountain chains do not occur except where there is a great thickness of sedimentary deposits, and that these become plicated by their own subsidence. Hence plication is characteristic of all mountain chains; so, also, is metamorphism, for in the subsidence the material has been brought into such relations of position as to cause the isothermal planes to ascend into it, and thus to bring it into such conditions of temperature as to facilitate those chemical changes which result in converting a sedimentary into a metamorphic rock. Hence, also, a synclinal structure and an axis of metamorphic rocks are to be expected in every great mountain chain. But how the mountain chain is obtained from the depressed mass of strata is nowhere explained by the author of the theory in question; hence it has been aptly characterized by Professor Dana as "a theory for the origin of mountains, with the origin of mountains left out." Indeed, there is no point in which it will stand the test of examination. It admits of mathematical demonstration that the assigned cause would not be sufficient to cause the plication. This can also be made apparent to the eye by drawing a diagram representing a section of a portion of the earth's crust on a natural scale, laying off an area of subsidence with an amount of depression equivalent to the assumed thickness of the stratified rocks, say of the Appalachian chain, and observing the relative length of the lines representing the original surface and that of the depressed mass. The result will be quite conclusive as to the plication of strata from their own subsidence, except where that subsidence is extremely local. Neither is it true that mountain ranges exhibit usually anything like the kind of synclinal structure required by Professor Hall's theory; indeed, if we can understand what this structure would be most likely to be, there is no such chain anywhere. The theory, as set forth by its author, is left in such a vague form that it seems impossible to bring it to any crucial test, and one has to be content with finding in it nothing which will bear examination.

It must be borne in mind also, in this connection, that neither Babbage nor Herschel were geologists, and that, consequently, their views with regard to the relative importance of different geological agents or conditions are not to be accepted without careful investigation. A little consideration will show that although there may be something plausible, and even attractive, about these theories of metamorphism and change of relief of the surface in consequence of denudation and the accumulation of sediments, the facts are far from supporting them, at least to anything like the extent assumed by Professor Hall. If the earth's crust is so sensitive to pressure that it is ready to respond to the very gradual and comparatively slight difference of level resulting from abrasion of the rock at one locality and removal of the detritus thus formed to another, how is it that the weight of the great mountain masses is supported, or how could they have originated at all? It is not possible to conceive that, during all the preceding stages of the earth's existence, its interior should be so insensible to the pressure of the crust as to allow ranges like the Alps, the Andes, and the Himalayas to be built upon it, and that, at the present epoch, it has, all at once, assumed such a condition of sensitiveness as to respond by its motion to any transference of weight from one region to another. It would not be difficult to suggest other valid reasons for refusing to accept Herschel's views; but enough has been said to indicate clearly that they are not admissible as a basis for orographic generalizations. The ideas of Babbage in regard to the rise of the isogeothermal planes in consequence of the accumulation of sediments are more philosophical than those of Herschel; but the facts do not bear us out in inferring that extensive metamorphism will necessarily be the result of the resulting increase of temperature. An examination of a section of stratified rocks piled upon each other to a height of several thousand feet, resting horizontally on the granite, and quite unaltered as to texture since deposition, is sufficient evidence that heavy accumulations of sediment are not necessarily rendered crystalline by the rise of the isogeothermal planes; but that something else is required to bring about that complex series of chemical changes which we designate by the term "metamorphic action." Such sections as those alluded to here may be seen in abundance over a wide area in the Rocky Mountains, and along the Colorado and its tributaries, as well as elsewhere. Indeed, the Appalachians and the Juras themselves show that great masses of rock may be piled up, and even extensively plicated, with but little resulting metamorphism.

The gist of Professor Hall's theory seems to be, that mountains are logically connected with large deposits of sedimentary rocks; and this is true, but exactly in the opposite way from that imagined by him. The sedimentary beds are thick because the mountains pre-existed from the destruction of which they could be formed; not that, having been already formed, they were afterwards made into mountains. There can be no formation of detrital or sedimentary deposits, that is, of stratified rocks, without the previous existence of some higher region from which the material can be derived. Hence, if the combined thickness of the sedimentary beds about a great mountain centre reaches a high figure, it is simply because the conditions for the accumulation of such beds have been favorable. With a surface entirely flat, the amount of deposition must necessarily be very small and almost entirely confined to such materials as are produced by chemical or organic action. But those beds which are chemically precipitated or formed by living organisms are vastly inferior in thickness to those which result from the piling up of detrital materials, or such as are abraded from previously existing rocks through the agency of water.

It is evident that, in theorizing in regard to mountain-making and deposition of sediments, too little regard has been had to the origin of these sediments. The fact is ignored that all the sedimentary formations must have been originally derived from the original crust of the earth as it existed after cooling had gone so far that water had begun to condense upon its surface; they must have had some higher region from which to be swept downwards. These higher regions were, in the first place, evidently the ridges or wrinkles of the granitic and gneissoid crust raised above the general level by the first efforts of the consolidated crust to adapt itself to the interior. The detritus thus carried down the flanks of the ridges was, early in the geological history of the earth, mostly deposited in the ocean, which must originally have covered even a larger portion of our surface than it now does. Hence the predominance, or almost exclusive existence, of marine formations, during the earlier geological ages. It was not until a large body of sedimentary deposits had thus been formed, and these masses had begun to be themselves raised above the sea-level, that their abrasion could furnish material for a set of beds not derived from the original crust. And this process having once been gone through, the same thing may have been repeated again and again. How many times such a destruction of pre-existing sediments and formations of new deposits from the ruins may have taken place in any one region, we cannot say; but we have no reason for assuming that all over the world this has gone on to such an extent that none of the original crust can be anywhere visible.

The area of the continental masses gradually and constantly expanding, and the depth of the oceanic basins increasing, strata formed by fluviatile action began to be deposited, and of course contained the remains of fresh-water and land animals. If, then, no new axis of elevation was originated, and there was no further rise of the land, the formation of new stratified deposits would eventually reach its limit, because the newly formed beds would have risen to the level of the highest existing land, and, equilibrium of the surface having been restored, there could be no more erosion, except on the smallest scale. Thus, in many mountain chains, as already noticed, there has been a cessation of growth at an early period; while in others — and these are the great chains of the world — growth has continued down even to the very latest epoch. In these instances of continued growth there has usually been a tendency to the formation of a new axis or uplift parallel with the earlier one, and at no great distance from it, on one side or the other. Thus opportunity has been given for the processes of abrasion and reconstruction of strata, and the mountain mass has developed itself, until we have, as the final result, a series of approximately parallel ranges, showing in their structure the complicated nature of the processes by which they have been formed.

This method of growth by lateral aggregation is most admirably exemplified in the Cordilleras of North America. In this complex of chains, we have, first, the granitic and gneissic nucleus or basis, which is the floor on which all the stratified formations have been laid down, and from whose ruins the bulk of the materials have come for building up the ranges. This ancient nucleus is, in places, low down and concealed by heavy masses of stratified formations; in other regions raised into lofty crests, possibly the highest of the whole series. The stratified deposits, which have been formed from this nucleus, have been, from time to time, folded, upheaved, and invaded by eruptive rocks, whose distribution, however, has been very irregular.

On the western or oceanic side the disturbances have been most extensive. Here the upturnings and crushings of the strata have taken place on the grandest scale, and new axes of elevation have been formed at successive geological epochs, the close of the Jurassic and of the Miocene tertiary being two of the most important of these. On the eastern or Rocky Mountain side no great folding or metamorphism of the rocks occurred after the close of the Azoic period; but a gradual elevation of the whole mass of strata took place, the larger portion of which was during the Tertiary epoch. By this uplift the unaltered cretaceous rocks were raised to an elevation in places greater than ten thousand feet above the present sea-level. This rise of the land continued until the most recent geological times, or almost down to the present day; but how much of the difference in elevation between the land and sea is due to actual positive uplift, and how much to a sinking of the ocean, we have at present scarcely any means of judging. At all events there were, on this side of the Cordilleras, almost no local disturbances or foldings of the sedimentary rocks, which still lie upon each other in regular sequence, dipping at a low angle from the central crystalline masses everywhere, except just at the line of junction of the two formations, where, for a distance of a few thousand feet at right angles to their trend, the stratified formations, from Silurian to Carboniferous, are turned up on edge in the most wonderful manner, and sometimes completely overthrown, so as to dip towards the mountains, but not metamorphosed or rendered crystalline in structure. Neither were these disturbances attended, to any considerable extent, by outbursts of volcanic or eruptive material; while on the western side of the continent these occurred on the grandest scale.

An examination of all that has been published with regard to the geology of the Andes indicates that when this mighty chain of mountains comes to be thoroughly studied, there will be many analogies discovered between them and the North American Cordilleras. Some such could already be indicated if space permitted ; but, as yet, no careful section has ever been made across the South American ranges by any trained stratigraphical geologist.

In the case of the Appalachians, we have to do with a chain of mountains which has no crystalline centre or axis, and which consists, at least through a great portion of its length, of a pile of detrital materials, distinctly stratified, all belonging to the Palæozoic epoch, scantily provided with fossils, but separable into a number of well-marked groups by the aid of lithological characters. These groups have much their greatest development towards the northeast and southwest, and they dip in general towards the west or northwest, so that in going in that direction we rise on to more recent strata. Proceeding westerly, moreover, we find the plications, which are well marked on the eastern edge of the chain, gradually disappearing; while at the same time the groups of strata are found to be made up of finer materials and to be gradually thinning out, thus indicating a greater distance from the source from which the detritus of which they are made up was derived. Hence we can hardly fail to draw the inference that this source was somewhere to the east of the range, and that the region from which the plicating force proceeded is also to be sought for on that side. If this be the case, then it seems probable that there must have been a high range of crystalline rocks on the eastern borders of the Appalachians, for there is no other conceivable source of supply which would satisfy the required conditions. The detritus of which the rocks of this range are made up came then from a higher region, which has since disappeared. It must have subsided, and this subsidence was, as we conceive, the cause of the plication of the beds which had been formed on its western slopes, these beds having been elevated and crumpled or flexed as the mass exterior to them was gradually sinking.

Subsidence, then, we regard as the chief cause of the plication of strata; but it is not the sinking of the stratified mass itself which is the principal effective agent in bringing about its folding. There can be no plication, to any appreciable extent, without an actual shortening of the plicated strata, and this can only come from a lateral thrust, such as would be exerted by a subsiding mass upon a region exterior to it. Hence if we find the newer strata on the flanks of an older central nucleus compressed together by folding, we are justified in presuming that it is the subsidence of the latter which has given rise to the plication of the adjacent lower region. If the subsiding higher area be of comparatively large dimensions, there will be a tendency to produce elevation to a certain extent on each side.

The folding of the newer strata along the base of the Alps, and of the Jura even, has repeatedly been explained by successive upheavals of the Alpine masses; indeed, these have been taken for granted by most geologists, without any attempt to investigate the manner in which the assumed cause could bring about any such result. It is certainly clear enough that elevation of the central mass would produce a lengthening rather than a shortening of the base on which rest the strata which are uplifted, and that this is something quite the opposite of what is required to cause plication. From a careful study of the stratigraphical geology of the Sub-Himalayan ranges, Mr. Medlicott, of the India Survey, was led to the conclusion that the peculiar position of the rocks of which those mountains are made up could only be accounted for on the theory of a subsidence of the central mass, and the same idea has been applied by him to explain the contortions of the tertiary beds on the flanks of the Alps, as well as to plications of stratified rocks in general.* And so far as this geologist has developed his ideas on this subject, they are identical with those formed by us in studying the mountain systems of North America.

We have thus endeavored to give an idea of the progress making by geologists in getting towards a solution of some of the principal problems of orography. The subject is a very comprehensive and difficult one, and it is far from easy to treat it in a popular manner. It is evident that much remains to be done in this line of research, and that it is desirable that chemists and physicists should lend a helping hand; but the burden of the work must fall on the geologists, and one important step will have been made when it is clearly recognized that geological facts must be allowed to have more weight than chemical theories, and that a large experience in the field is a necessary prerequisite to valuable theorizing.

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* See Quarterly Journal of the Geological Society of London, XXIV. 34.

J. D. WHITNEY.

ART. II. — THE REGENERATION OF ITALY.

To think of Italy is a habit which we contract very early in life. Many school-boys know more about Rome than about the capital of their native land. But there is no great harm in this partiality for the classical world; and pedagogues rarely object to it on moral or patriotic grounds, though they may have to urge against it the daily increasing claims of the exact sciences and the shortness of life. If the ideal world of our boyhood has Rome and Athens for capitals, are we not better off than our sisters whose world revolves round Paris, with occasional nutations towards Jerusalem?

Not only do we owe much to the Latin races of the Italian peninsula themselves, but even the subtler and remoter influences of Grecian culture have reached us mainly through the medium of the Latin world which outlived both the Grecian and the Byzantine world. It stretches across the gloom and confusion of the Middle Ages with a majestic continuity, not broken by defeats or by invasions. With new gods and a new language, it was still Latin in the thirteenth century, and its decrepitude led to nothing worse than to its *renaissance*. Nay more, the Empire that was officially reported dead in 1806 had still the pretension of being, somehow, the Roman Empire, and, until 1870, the so-called Catholic world has never ceased to have its secular capital in Rome. In fact, a more imposing case of historical continuity could not be found, except in the annals of Egypt and of China.

That the hard-working sons of the North should look fondly and longingly on the Italian peninsula, on all that is in it and